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Review article

# Intravenous magnesium administration errors, attributing factors and associated respiratory or cardiopulmonary arrest in obstetric and non-obstetric patients—A systematic review

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ABSTRACT

*Background:* The primary objective of this systematic review was to investigate intravenous (IV) magnesium administration errors and associated adverse outcomes in hospital settings. The secondary objective was to identify contributory factors using the human factors and analysis classification system (HFACS) framework.
*Methods:* PubMed, Scopus and Google Scholar were searched using the systematic search protocol for the past five decades. Magnesium administration errors were included, provided the route of administration was IV, and the clinical outcomes were described. Reports of errors *via* other routes were excluded.
*Results:* The search identified 32 reports (31 obstetric and 15 non-obstetric patients). Errors occurred in wide-ranging locations. Most errors (36 of 46) occurred during maintenance dose infusion. For obstetric patients, errors occurred in patients with preeclampsia ($n$ = 24) or preterm labour ($n$ = 7) during varying periods of pregnancy. In four women, perimortem (2 patients) or within a few hours of cardiopulmonary resuscitation, lower segment caesarean sections were performed. Nearly two-thirds (63%) of patients developed either respiratory arrest only (9 obstetrics and four non-obstetric) or cardiopulmonary arrest (10 obstetrics and six non-obstetric). The permanent harm occurred in six patients (death −3 and vegetative state −3). Most contributory factors were skill-based errors, adverse mental state, communication and coordination of care, and deficiencies in magnesium-related processes.
*Conclusions:* The findings highlight the need for improved IV magnesium administration practices across wards and acute care settings. Standardisation of magnesium products, their labelling, preparation, as well as reliable monitoring processes during the therapeutic use of magnesium, are essential to prevent magnesium infusion errors.
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## Introduction

Intravenous (IV) medication administration is a common practice in hospital settings for medical, surgical, and obstetric patients. Many of these patients are in critical condition, requiring urgent intravenous medication administration while doing other clinical tasks. The administration of IV medication requires multiple procedural steps (*e.g.*, prescribing, picking up, preparing, administering, and monitoring) to ensure the safe execution of the complete task and avoid associated adverse outcomes. IV route medication errors are common, particularly in administration type, and may lead to severe morbidity and mortality [1]. The practices of preparation and administration of IV medications are variable and vulnerable to human and systemic deficiencies [2].

Furthermore, supportive physical and technological facilities, such as storage, admixing, infusion pumps, monitoring, and documentation, may also influence patient safety during the IV administration of medications [3]. These processes can be further complicated and may increase the risk of mishaps when the modes of administration are combined (*e.g.*, bolus followed by infusion). For example, one study showed that errors and discrepancies are

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relatively common in everyday infusion administrations, but most have a low potential for patient harm [4]. Moreover, IV medication use is a collaborative effort involving multiple professionals, including doctors, nurses, midwives, and pharmacists, who provide services in various locations, such as wards, operating rooms (OR), emergency departments (ED), and critical care units. Each professional's role is crucial in ensuring the safe administration of IV medication.

High-alert medications, a category that includes drugs associated with a heightened risk of causing significant patient harm when an error occurs, demand utmost vigilance and adherence to safety protocols. Although there is no data on the frequency of mistakes with these drugs, the consequences of an error are more likely to be devastating to patients [5]. Magnesium, a high-alert medication, is indicated in many clinical conditions. For example, therapeutic use of IV magnesium in the adult population for acute problems in obstetric, respiratory, cardiovascular, anaesthesia, pain, and neurology specialities [6–10]. Another indication is correcting hypomagnesemia in acute care settings, such as intensive care units (ICUs), emergency departments (EDs), and operating rooms (ORs). Accordingly, magnesium ampoules, vials, and premixed infusion bags are stored along with other medications and IV fluids in the wards, including labour and busy clinical care locations. Depending on the local hospital policy, the care provider may prepare a magnesium bolus or maintenance infusion at the point of administration. Patients may require a transfer from one acute location to the routine ward or *vice versa* (*e.g.*, from the emergency department to the antenatal ward or from the delivery suite to the operating room) while an IV magnesium infusion is ongoing.

The fact that magnesium sulphate (MgSO4, now also referred to as magnesium) is available in ampules or vials containing a wide range of concentrations creates significant risks for medication errors, predisposing not only to mix-ups with other medications but also to the selection of the appropriate magnesium vial, ampule, or infusion bag. A comprehensive review of IV magnesium administration errors is lacking in the literature. Therefore, the current study aimed to identify the clinical characteristics, potential severity, and outcomes of IV magnesium administration errors. The secondary objective was to identify systemic and human contributory factors and possible areas of improvement to prevent.

## Methods

The author systematically searched PubMed, Scopus, and Google Scholar for published reports of intravenous magnesium errors in humans from 1976 to January 2025. There was no language or restriction applied. For PubMed, a combination of MeSH term and keywords were used to formulate a search query: (("intravenous" [TIAB] OR "IV" [TIAB] OR "infusion" [TIAB] OR "overdose" [TIAB] OR "life-threatening" [TIAB] OR "toxicity" [TIAB] OR "therapy" [TIAB] OR "administration" [TIAB]) AND ("accidental" [TIAB] OR "iatrogenic" [TIAB] OR "inadvertent" [TIAB] OR "medication error" [TIAB] OR "apnoea" [TIAB] OR "arrest" [TIAB] OR "respiratory" [TIAB] OR "ventilation" [TIAB] OR "cardiopulmonary" [TIAB] OR "resuscitation" [TIAB] OR "harm" [TIAB] OR "lethal" [TIAB] OR "hazards" [TIAB]) AND ("magnesium" [TIAB] OR "magnesium sulphate" [TIAB] OR "hypermagnesemia" [TIAB] OR "hypermagnesaemia" [TIAB] OR "hypomagnesaemia" [TIAB] OR "hypomagnesemia" [TIAB] OR "MgSo4" [TIAB])). The detailed database search strategy is described in Supplemental File 1. For Google Scholar, articles were also searched using "related articles" and "cited by" links. We manually searched references from the eligible articles to identify additional magnesium error reports. We included all language articles. The PRISMA checklist is included in the Supplemental File 2.

The author included publications that reported one or multiple errors during the therapeutic use of magnesium, provided the route of administration was intravenous (IV), and the report described the final clinical outcome. The author included error reports that described mishaps during loading dose (bolus) and infusion (from the start or following a loading dose) administration errors in any hospital location (*e.g.*, wards, acute care areas). The author excluded reports of errors *via* other routes than the IV route (*e.g.*, oral, intrathecal, epidural). IV magnesium side effects or toxicity due to the exaggerated effects of magnesium in the presence of specific medical problems (*e.g.*, renal failure, neuromuscular disorders) were excluded. The author also excluded reports where iatrogenic hypermagnesemia was suspected, but the potential cause was not clear.

The author categorised the population involved into obstetric and non-obstetric groups. For each of these two groups of patients, age, indication for magnesium use, clinical location, mode of administration (bolus or infusion), and the dose of administration were recorded in a standardised format. When an error occurred in one place but was detected in another or when magnesium was administered safely in one location but subsequently occurred in another following patient transfer, both locations were recorded. We documented clinical circumstances, clinical features, investigations, and consequences of magnesium administration errors. We also recorded other medical conditions considered during differential diagnosis, as described in the reports.

For adverse outcome analysis, the author focused on serious sequelae in the form of life-threatening (defined as if the event causes systemic features that, if not treated, would result in death), respiratory arrest, or cardiopulmonary arrest. The permanent adverse outcomes were classified as death or vegetative state requiring life-long dependent care.

Finally, the author applied the human factors analysis classification system (HFACS), based on James Reason's Swiss cheese model, to classify contributing factors into four main categories, each further classified into a variable number of subcategories. The three categories include latent deficiencies (organisational issues, unsafe supervision, preconditions for unsafe acts), and the last is active failures categorised as unsafe acts. Each main category has several subcategories to include a wide range of potential factors present before or during the incidents. Analysis of the incident characteristics and HFACS data was performed using frequency counts.

## Results

As shown in the PRISMA flow chart, 46 patients are included for analysis (Fig. 1). There were 31 obstetric [11–31] and 15 non-obstetric patients [32–42]. In non-obstetric patients, 4 of 15 patients were paediatric (including two premature and two infants) [37–39], and four were geriatric (age $\geq$ 65 years) [32,34,35,41]. Some reports contained more than one incident [24,31,32,36,37].

Table 1 summarises the indication for magnesium therapy, location of incidents, mode of therapy when the error occurred (during loading or maintenance dose infusion), and

outcome for obstetric and non-obstetric patients. For obstetric patients, diagnosis at the time of error, pregnancy stage, and its outcome are included in Table 2. Supplemental File 3 (Table) summarises the individual patient's clinical features, main investigations, highest reported magnesium level, management, and outcome for non-obstetric patients.

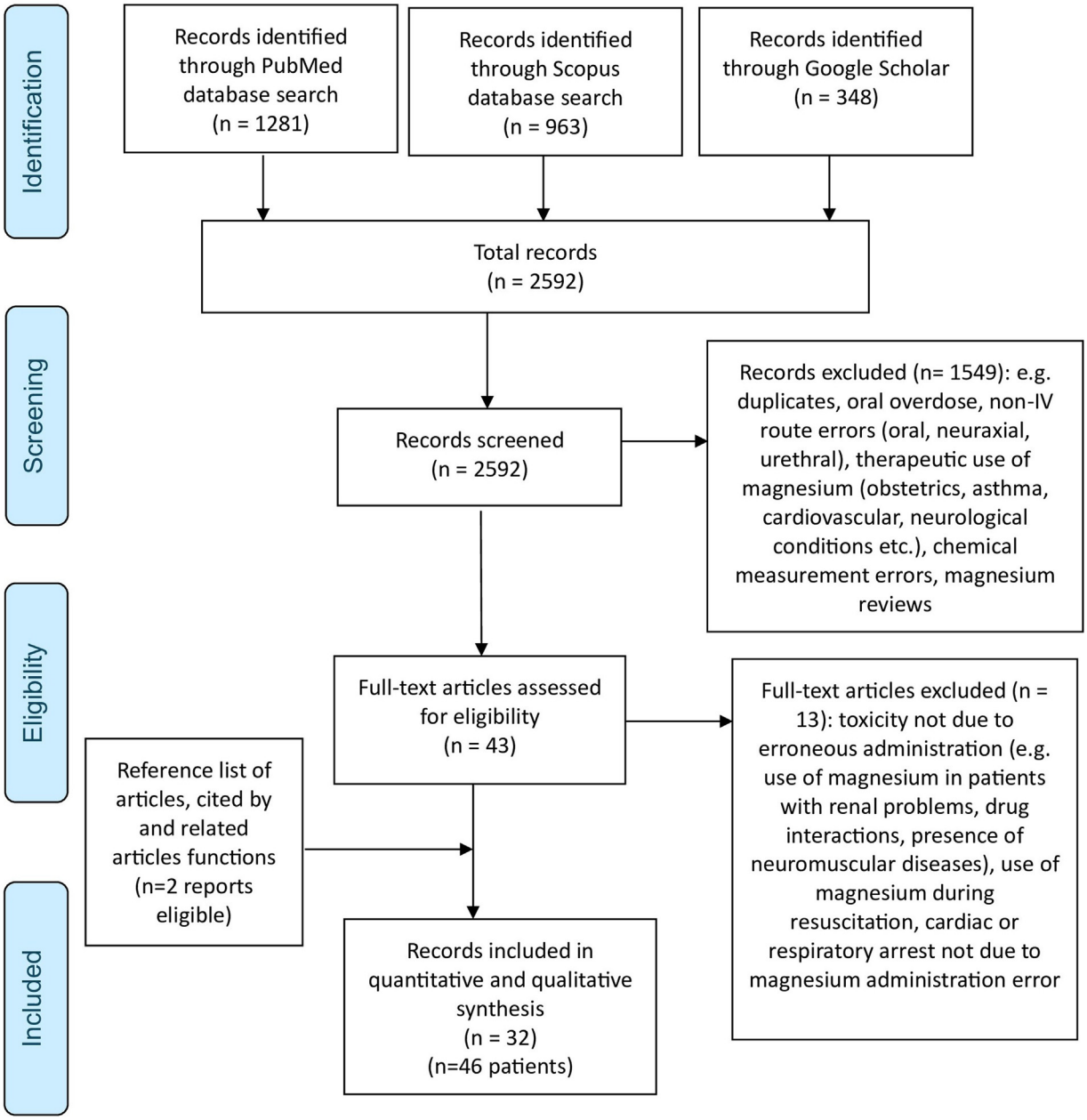


**Fig. 1.** Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram for the intravenous magnesium administration incidents. In this figure, records excluded number should be read as 2549 in place of 1549.

*Indication*

*Obstetric*

Magnesium was administered either for preeclampsia ($n$ = 24 of 31, 77.4 %) [11–14,6–17,19–26,28–31] or preterm labour ($n$ = 7 of 31, 22.6%%) [15,18,27,31] (Table 1). Among women with preeclampsia, the severity, dose of magnesium administered, protocol for magnesium bolus and infusion administration, and monitoring were variable. In patients with preterm labour, magnesium was used predominantly as a tocolytic agent [15,18,27,31].

*Non-obstetric*

The predominant indication was hypomagnesemia associated with a variety of critical illnesses [32–34,36,38,39,41]

*Location*

The incidents occurred in routine wards (maternity, medical, surgical, oncology, and paediatric) and acute care areas, such as the labour ward, ED.

*Obstetrics*

Two locations involved nearly one-third (10 of 31) of obstetric errors [17,19–21,24,30,31]. For example, the error occurred in one area but was not detected until after the patient was transferred to another location (*e.g.*, from the ED to the maternity wards or ICU). For some patients, magnesium was safely administered at one location. Still, errors occurred during transfer (*e.g.*, from the recovery room to the postnatal ward [17], from the ED to the

**Table 1**
Indication, Locations, Mode of therapy, Differential diagnosis and Outcome associated with IV magnesium administration errors.

| | Obstetric ($n$ = 31 patients) | Non obstetric ($n$ = 15 patients) |
|---|---|---|
| Indications | • Preeclampsia: 24 [11–14,16,17,19–26,28–31]<br>• Preterm labor: 7 [15,18,27,31] | • Hypomagnesemia: 8 [32,34,36,38,39,41]<br>• Cardiac: 1 atrial fibrillation and 1 suspected acute myocardial infarction [32,35]<br>• Erroneous preparations of total parental nutrition: 2 [37]<br>• Incorrect infusion bag (in place of potassium chloride): 1 [40]<br>• Not clear: 2 |
| Location | • Two locations (occurrence and detection different locations including involving intrahospital and interhospital transfers): 10 [17,19–21,24,30,31]<br>• Maternity wards (Delivery suite/labour ward, antenatal or postnatal ward): 8 [15,16,26,27,31]:<br>• OR: 4 [21,23,24,29]<br>• ED: 4 [18,24,28,31]<br>• Unclear/Not mentioned: 5 | • Wards (medical/surgical/hemato-oncology/neonatal): 8 [32,38,39,41,42]<br>• ED: 5 [32,35,36,40]<br>• ICU: 1 [33]<br>• Two locations (occurrence and detection different locations): 1<br>• Unclear/Not mentioned: 1 |
| Bolus or Infusion | • Bolus (loading dose administration): 10 [11,12,14,19,24,27,28,31]<br>• Maintenance dose infusion: 21 [11,13,15–18,20–23,25,29,31] | • All infusions (without loading dose): 15 [31–42] |
| Considered differential diagnosis during iatrogenic hypermagnaesemia | • Intra-cranial aneurysm, Metabolic, Eclampsia [11]<br>• Suxamethonium apnea [23]<br>• Delayed recovery [25]<br>• Pulmonary embolism, amniotic fluid embolus, cerebral edema, maternal stroke or seizure [26]<br>• Epilepsy, cerebral haemorrhagic event, metabolic or toxic encephalopathy, and ischemic stroke [28]<br>• Hypoxic-ischemic encephalopathy [29] | • Central brain-stem syndrome as a rare complication secondary to cerebral edema [33]<br>• Septic shock syndrome [37]<br>• Stroke, Seizures, Cerebral metastases (in the presence of cancer) [41]<br>• Anaphylaxis [42] |
| Respiratory or Cardiac arrest | • Respiratory arrest]: 9 [13,15,17–19,26,29,31]<br>• Cardiopulmonary arrest: 10 [11,12,14,16,20,22,27,28,31] | • Respiratory arrest: 4 [33,35,37]<br>• Cardiopulmonary arrest: 6 [32,34,36,38,40] |
| Final Outcome | • Death: 2 [12,31]<br>• Vegetative: 2 [31]<br>• Survival: 27 | • Death: 1 [36]<br>• Vegetative: 1 (anoxic brain injury) [32]<br>• Survival: 13 |

ED-emergency department, OR-operating room, ICU-intensive care unit.

maternity ward, OR, or ICU [19,27], and from the maternity ward to the OR [20]).

*Non-obstetric*

The highest number of medication errors occurred in the following departments in order: wards ($n$ = 7), followed by ED ($n$ = 5).

*Mode of administration*

Most administration errors occurred during the magnesium maintenance infusion in obstetric and non-obstetric patients. None of the mistakes was due to malfunctioning devices.

*Obstetric*

In 10 pregnant women, errors were reported during the bolus administration stage due to wide-ranging causes (*e.g.*, uncontrolled infusion, or miscommunication of prescription) [11,12,14,19,24,27,28,31].

*Infusion*

In 21 (of 31) patients, magnesium maintenance infusion incidents were attributed to wide-ranging causes [11,13,15–18,20–23,25,29,31]. For example, the magnesium administration set remained connected without the pump, leading to free flow during transfer, failure to disconnect the IV magnesium infusion set once it was no longer needed, assumption about the verbal order or prescribed dose, wrong calculation of the infusion rate, and inadequate monitoring during bolus or maintenance infusion therapy. In one obstetric case, an error occurred despite using a smart infusion pump because the nurse was unfamiliar with its functions.

*Non-obstetric*

The maintenance (without a loading dose) infusion was the initial mode of therapy for all patients [32–42]. In four paediatric patients [37–39], infusion complications occurred because 40 g of magnesium sulphate was administered in place of 4 g [38], ten times the recommended dose [39], and an automated total parenteral nutrition mixing device malfunctioned [37]. Most reports did not describe the type of infusion device or rate regulation [32–36,38,40,33–42].

*Outcome*

*Obstetrics (Table 2)*

Of 20 antenatal women who received erroneous magnesium, two underwent perimortem LSCS [22,28], one immediately after cardiac resuscitation in OR [20] or one [12] or 12 h after [11] cardiopulmonary resuscitation. The contributory factors in these

**Table 2**
Diagnosis, weeks and period of pregnancy and outcome following IV magnesium administration errors in 31 obstetric patients.

| Reference | Weeks of pregnancy/Diagnosis | location | Pregnancy period during Mg error | comments |
|---|---|---|---|---|
| [11] | 37/PET | Unclear | Antenatal | Cardiac arrest. 12 h. after the event LSCS. |
| [12] | FT/PET | Unclear | Antenatal | Cardiac arrest. LSCS 1 h. after the event. Death after 4 days. |
| [13] | 27/PET | Ward | Postpartum-post LSCS | 18 h post LSCS, when the patient was moved, the infusion set was disconnected from the infusion pump and not replaced. |
| [14] | 32/Eclampsia | Unclear | Antenatal | Cardiac arrest. Post resuscitation pregnancy continued. LSCS at 36 weeks. |
| [15] | 32/PTL (tocolytic) | Not mentioned | Antenatal | Few hrs after the incident spontaneous delivery of twins. |
| [16] | 39/PET | Ward (labour) | Postpartum- shortly after ND | The infusion pump was disconnected |
| [17] | 38/PET | Transfer | Postpartum-post LSCS | On arrival from recovery room.to postpartum ward. |
| [18] | 26/PTL (tocolytic) | ED | Antenatal | Admixing problem. R/R – 5/ minute. Normal pregnancy continued. |
| [19] | Not reported Eclampsia | Transfer | Postpartum- 17 h after ND | On arrival in ICU, collapsed due to uncontrolled infusion during transfer |
| [20] | 36/PET | Transfer | Antenatal | Immediate after cardiac arrest in the OR- LSCS performed after resuscitation. |
| [21] | 33/PET | Transfer/OR | Antenatal | Unlabelled infusion bag continued in the OR. Error detected after baby delivery. |
| [22] | 40/Eclampsia | Labour ward | Antenatal | Perimortem LSCS. Uncontrolled rapid infusion. |
| [23] | 32/PET | OR | During LSCS after delivery of the baby | Instead of increasing the infusion rate of oxytocin the anaesthetist increased the magnesium infusion |
| [24] (two patients) | Not reported/ 1-PET, 2 Eclampsia | 1-OR<br>2-Transfer | 1-During LSCS<br>2- Antenatal (from ED to LR) | First case emergency under general anaesthesia.<br>In both cases, infusion rate was not decreased following bolus dose administration. |
| [25] | 36/PET | ED | Antenatal | LSCS within few hours of the error. Delayed recovery from anaesthesia. |
| [26] | Not reported/Severe PET | Ward (postnatal) | Postpartum (normal delivery of twins) | During management of PPH, uncontrolled magnesium administration in place of oxytocin. |
| [27] | 27 / PTL | Ward (labour) | Antenatal | Several days after the event LSCS because of unrelated complications. |
| [28] | 31/Eclampsia | ED | Antenatal | Perimortem LSCS. |
| [29] | Full term/PET | OR | Postpartum-post LSCS | Mg infusion mistaken for normal saline during re-exploration for bleeding after LSCS. |
| [30] | 31/PET | Interhospital transfer | Antenatal | Confusion about measured magnesium plasma levels which affected the infusion rate. |
| [31] | Patient 1: PTL | Transfer | Postpartum (shortly after ND) | Soon after delivery, instead of oxytocin, rapid magnesium infusion. Vegetative state. |
| | Patient 2: PET | PP ward | Postpartum (12 h after ND) | The patient received two magnesium infusions simultaneously. Vegetative state. |
| | Patient 3: PET | Transfer | Antenatal | Inexperienced nurse increased the infusion rate from 2 g/h to 7 g/h during interhospital transfer |
| | Patient 4: PET | Labour ward | Antenatal | Inadequate handover led to increase in magnesium infusion rate (from 2 g/h to 4 g/h). |
| | Patient 5: PET | . Not reported | Antenatal | Verbal order and inadequate handover led to administration of two bolus doses. |
| | Patient 6: PET | Not reported | Antenatal | Misreading of labels led to admixture of 80 g then expected 40 g in 1 L bag. |
| | Patient 7: PTL | Not reported | Antenatal | Unlabelled infusion bag contained 40 g which was infused at 300 mL/h. Death. |
| | Patient 8: PTL | Not reported | Antenatal | Pump infusion rate not decreased after administration of bolus dose completion. |
| | Patient 9: PTL | Transfer (ED to Tertiary centre) | Antenatal | The nurse misinterpreted an order and added Mg in the premixed bag of normal saline with Mg. |
| | Patient 10: PET | Transfer (ED to PP ward) | Post-partum (4 days after ND) | Incorrect calculation of the magnesium infusion rate. |

PET-preeclamptic toxaemia, PTL- preterm labour, LSCS- lower segment caesarean section, Mg-magnesium, g-gram, R/R-respiratory rate, ICU-intensive care unit, OR-operating room, ED-emergency department, LR- labour room, PP-postpartum, ND-normal delivery, PPH-postpartum haemorrhage.

patients included imprecise and confusing labelling [28], lack of infusion pump resulting in 16 G administration within few minutes [22], 20 g loading dose in place of 4 g vial due to storage of 1 g and 5 g magnesium vial nearby [11], hospital's magnesium use and infusion policy violation during transfer from delivery suite to OR (infusion pump alone was removed from the IV line, allowing a free flow infusion) [20].

In nine postpartum women, the error occurrence timing was immediately, or a few hours or a few days after normal vaginal delivery [13,16,17,19,26,29,31].

*All patients*

Nearly two-thirds (63%, 29 out of 46) of patients developed either respiratory arrest (obstetrics 9 and non-obstetric 4) or cardiopulmonary arrest (10 obstetrics and 6 non-obstetrics). In cases of respiratory arrest only, management varied for obstetric patients, including oxygen therapy [18], bag-mask ventilation [15,17], or tracheal intubation [13,16,19,26]. All four non-obstetric patients with respiratory arrest only required tracheal intubation and mechanical ventilation [33,35,37] (Supplemental File 3 (Table)).

The permanent adverse outcomes were reported in the form of death (3 patients -2 obstetric and one non-obstetric) [12,31,36] and vegetative state (3 – 2 obstetric and one non-obstetric) [31,32].

*Differential diagnosis (Table 1)*

Wide-ranging clinical conditions were considered in the presence of acute iatrogenic hypermagnesemia (Table 1).

*Human factors analysis and classification system data (Table 3)*

The frequency of contributory factors for each subcategory of the four main categories of the HFACS is identified in the table (Table 3).

Of skill-based errors, the majority involved some attentional or memory failure, for example, failing to reduce the infusion rate once the bolus dose was completed. Perceptual errors were

**Table 3**
Contributory factors and their frequency for intravenous magnesium administration errors identified using the Human Factors Analysis and Classification System framework*. N1 and N2 frequency for obstetric (31 patients) and non-obstetric (15 patients) respectively.

| | Sub-categories | Examples | N1 | N2 | Refs |
|---|---|---|---|---|---|
| Organizational 35 (27 + 8) | Climate | • Inconsistencies in Mg dosage recommendations<br>• Inconsistencies in Mg level reporting (multiple reports)<br>• Recurrent errors (multiple reports)<br>• Lack of maternal transport facility | 9 | 4 | [12–16,17,24,27,30–32,34,36] |
| | Process | • Vials with different Mg concentrations/amount available (*e.g.*, 1 g, 4 g, 5 g, 8 g, 25 g) (multiple reports)<br>• Procurement of look-alike ampoules, vials, infusion bags, pumps (multiple reports)<br>• Interhospital or intrahospital transfer deficiencies (multiple reports)<br>• The hospital pharmacy prepared identical Mg and oxytocin infusion bags | 15 | 4 | [11,14,19–21,23,26,27,31–34,38,40,42] |
| | Resources | • Education/training: Nursing, midwife<br>• Inadequate staffing | 3 | – | [27,31] |
| Supervision 6 | Inadequate | • Of untrained/inexperience staff | 2 | – | [27,30] |
| | Inappropriate planning | • Predominantly with regards to IV infusion set or for monitoring | 4 | – | [19,20,28,31] |
| Preconditions for unsafe acts 45 (32 + 13) | Tools/Technical | • Labelling issues (multiple reports)<br>• Presence of look-alike ampoules/vials, infusion bags, pumps in clinical locations (multiple reports)<br>• Intrahospital transfer of the patient without infusion pump from one clinical location to another (multiple reports)<br>• Failure to use technical function of the infusion pump<br>• Malfunction of total parental nutrition mixing device | 11 | 2 | [18,20,23,27,31–34,37] |
| | Physical environment | • Storage issues | 3 | 1 | [11,31,40] |
| | Mental state | • Attitude (*e.g.*, incorrect assumptions, complacency) (multiple reports)<br>• Distraction, haste,<br>• Multitasking | 10 | 1 | [20,23,26,27,29,31,41] |
| | Communication and coordination | • Verbal /written orders related to dose/prescription (multiple reports)<br>• Inadequate handover/transition of care (multiple reports) | 8 | 9 | [21,24,25,31–33,35,38,39] |
| Unsafe acts 56 (40 + 16) | Skill-based | • Uncontrolled rapid administration (multiple reports): infusion set disconnected and not replaced, drip regulator incorrect manipulation, administration *via* burette instead of pump<br>• Failure to reduce the infusion rate after loading dose<br>• Incorrect calculation of infusion rate<br>• Incorrect interpretation of prescription orders (multiple reports)<br>• Magnesium administration in place of oxytocin or normal saline<br>• Inexperienced staff did not operate infusion pump correctly<br>• Inadequate mixing of Mgso4 in a plasmalyte solution | 21 | 9 | [12,13,15–17,19,20,22–26,29,31,32,35,36,38–41] |
| | Perceptual | • Incorrect visual perception (multiple reports): *e.g.*, Mg ampoules/vials (4 g and 25 g, 4 g and 8 g), infusion bags (Mg and oxytocin, normal saline, 50% dextrose), pumps (*e.g.*, Mg and oxytocin) | 7 | 2 | [14,21,23,26,29,31,32,40] |
| | Decisions | • Failure or delayed inclusion of hypermagnesemia in differential diagnosis (multiple reports) | 8 | 5 | [11,23,25,28,29,31,33,35,37,39–41] |
| | Violations | • Failure to adhere to policy for patient transfer, storage, and monitoring | 4 | – | [19,20,27,31] |

Mg-magnesium, g-gram. Refs-references.

**Fig. 2.** Availability of confusing magnesium products in varying concentrations and quantities in ampoules, vials and infusion bags.

predominantly due to incorrect visual perception of magnesium vials of different concentrations and confusion due to look-alike infusion bags or vials. Violations were mainly routine, *e.g.*, failure to adhere to local policies related to transfer or monitoring. Decision errors were due to confusion about the clinical features of hypermagnesemia in relation to other critical obstetric or non-obstetric medical conditions.

One or more of the preconditions for unsafe acts were evident in almost all reports, except for the physiological state of the provider. While communication issues were common for obstetric and non-obstetric errors, adverse mental states and technological problems were predominantly present in obstetric errors. Adverse mental state (refer to the mental conditions of clinical staff that may affect performance) included both cognitive states, such as work-related distraction, multitasking, and lack of awareness, as well as personality-related problems, such as attitude-related (*e.g.*, assumptions about infusions, lack of verifications during hand-over) and complacency related to changes in clinical symptoms and signs. Communication and coordination issues involved included substandard prescribing practices, deficiencies in inter- and intrahospital transfers, and inadequate verbal and written handovers (*e.g.*, incomplete information about magnesium administration) of clinical care.

The most common organisational factor was a process-related issue, typically arising from inadequate procurement procedures for purchasing vials with varying concentrations of magnesium, even within the same hospital, which often had similar labels. Organisational processes and policies for preparing IV magnesium infusions, as well as several clinical aspects (*e.g.*, inter- or intrahospital transfers of patients receiving IV magnesium infusions), were not standardized. Inadequate staff training to handle the infusion pump was evident in one incident.

## Discussion

To the author's knowledge, the current study is the first systematic investigation of serious life-threatening risks associated with IV therapeutic use of magnesium in hospital settings, and aims to identify contributory factors applying the HFACS. Magnesium is available in multiple formulations, including 4%, 5%, 8%, 10%, 12.5%, 15%, 20% and 50% (Fig. 2). Furthermore, there are variable practices for preparing, dosing, and administering magnesium infusion [43]. Our investigation suggests that despite being considered a high-risk medication, recurrent problems existed at all HFACS levels, including skill-based errors, confusing magnesium products causing incorrect visual perception, inconsistent measurement units, substandard communication and transition of care practices, and poor organization processes and climate. In addition, the current investigation provides insight into the fact that errors can still occur, irrespective of the infusion device used, due to individual inaccurate assumptions, complacent attitudes, prescription-related issues, incorrect dilution, and a lack of technological knowledge about infusion devices. Many of these human and systemic factors are recurring and may persist. Multiple safeguards are necessary in working environments across the hospitals regarding the standardisation of concentrated magnesium sulphate products (*e.g.*, vials, ampules, infusion bags) and their availability for clinical use, infusion administration and discontinuation procedures, monitoring parameters (*e.g.*, sedation, respiratory, plasma levels) and intra or interhospital transition of patient care during therapeutic use of magnesium (Table 4).

During the preparation and administration of IV medication doses, the probability of making at least one error can be as high as 73% [44]. One multi-institutional observational study conducted in the USA and the UK revealed significant variability in practices and policies about IV infusion administration. It is a complex adaptive action involving humans (*e.g.*, providers and patients), technology (*e.g.*, hardware and software), and dynamic ward environments (*e.g.*, individual and team safety attitudes) within which it is carried out [45]. The evidence shows that infusion practices are not uniform among clinical areas; practical deviations are routine, and the availability and use of infusion devices are also inconsistent [4]. As a result, the error rate, contributory factors, consequences, and prevention strategies for

**Table 4**
Prevention of IV magnesium administration errors: Potential strategies and limitations.

| Step | Potential prevention strategies | Potential barriers |
|---|---|---|
| Manufacturing | Standardisation of products and labels: Magnesium is available in multiple formulations, including 4%, 5%, 8%, 10%, 12.5%, 20% and 50%. | No regulation<br>No incentive<br>Lack of awareness |
| Organizational processes / Climate | Safer processes include the procurement of magnesium products and preparation and monitoring during magnesium therapy.<br>Adequate staff to monitor patients receiving Mg infusion. | Accountability deficits<br>Cost<br>Lack of mechanisms to prevent recurrence |
| Labelling | Product labels standardisation to minimise confusion, *e.g.*, mg /mL, g/mL, %, w/v, total quantity (mg or g)/total volume (mL or L) (*e.g.*, in ampoule, or vial, or infusion bag)-Magnesium-specific, clear, high-alert / caution labels. | Lack of consensus and guidance for labelling Mg preparations<br>Similarity with other labels |
| Storage | Prohibiting storage in clinical areas of higher than 4% undiluted formulation.<br>Ergonomics to prevent selection errors. | Inadequate facility<br>Availability of look-alike other products |
| Prescribing | Changing the practice of undiluted prescriptions to prescribing diluted doses of Mg.<br>Electronic prescribing bundle for Mg | Required consensus among pharmacists, care providers |
| Preparation | Read labels before withdrawal from ampoules or vials<br>Avoid preparation of infusion bags with large quantities of magnesium.<br>Small volume (*e.g.*, 50–100 mL) commercial prediluted or pharmacy-prepared ready-to-use magnesium infusion syringes and bags.<br>Separate magnesium solutions are used for bolus dose and maintaining infusion. | Lack of consensus and guidance<br>Lack of double-check (human/barcode)<br>Economic burden<br>Confusing Mg products and labels |
| Pumps/devices for infusion | Prepare magnesium library protocol.<br>Automated programming of Mg dose (*e.g.*, infusion rate)<br>Advanced technological integration (*e.g.*, interfaced with barcode system and electronic health record).<br>Preparation of Mg in a syringe and administration *via* a syringe driver.<br>Audit Mg infusion pump-related safety practices. | Lack of availability<br>Lack of technological knowledge (*e.g.*, safety features)<br>Location-specific pumps<br>Lack of compliance |
| Administration | Double-check error-prone prescription, preparation, dose calculation, infusion device, and connection to IV catheter.<br>Identify IV and other route catheters and infusion pumps.<br>Impalement magnesium therapeutic care bundle involving stakeholders, including dose regimens.<br>Identify high-risk patients at risk for magnesium side effects.<br>Check available measures to manage magnesium toxicity. | Cognition capability (*e.g.*, attention, memory)<br>Incorrect assumptions<br>Working environment (*e.g.*, distractions, multitasking)<br>Violation of policy |
| Transfer | Standardise the transfer process for patients with magnesium infusion, *e.g.*, handling and monitoring infusions.<br>Do not disconnect the infusion set from the pump until indicated to prevent accidental free flow. | Hurry<br>Emergency surgery<br>Not familiar with infusion-related details |
| Transition of care (Handover of care) | Standardise the handover process for patients with Mg infusion: Check all details, including preparation, labels, dose, infusion rate, intravenous connections, patient progress, monitoring, and documentation. | Workload (caring for multiple patients)<br>Time pressures<br>Distractions |
| Monitoring | Standardise units of measurement: Mg plasma levels are reported as mg/dL, mEq/L mmol/L, *etc.*<br>Consider advanced respiratory monitoring in wards specifically for high-risk patients.<br>Familiarise with Mg side effects and follow local guidance. | Complacency with changes in clinical condition<br>No or insufficient tools for advanced monitoring |
| Reporting | Mechanisms to alert Mg-related incidents | No or inadequate system |
| Training / Education | Clinical features of magnesium toxicity.<br>Simulation drills to improve team performance on Mg toxicity. | Temporary staff<br>No resources |

Mg-magnesium, mg-milligram, ml-millilitre, g-gram, L-litter, mmol-millimole, dl-decilitre.

IV infusion errors vary among clinical locations, from hospital to hospital and among medications [4].

Furthermore, hospital infrastructure and resources available to implement corrective measures may vary significantly. For example, advanced technological solutions and strategies to mitigate high-risk infusion medication errors, such as barcode-enabled administration, smart infusion pumps, and clinical decision support systems for safer magnesium administration in pregnant women, may be challenging to apply in resource-constrained circumstances (*e.g.*, rural areas) and less developed countries. The current investigation underscores the need to identify and improve deficiencies in individual clinical areas. It reveals alarming vulnerabilities to errors at every significant procedural step of magnesium use (*e.g.*, prescription, preparation, initiation of infusion, and transition from bolus to infusion). The findings may contribute to overcoming barriers to unsafe practices and formulating safer pathways to minimise magnesium administration-related incidents [46,47].

To date, limited studies have focused on medication errors and contributing human factors in pregnant women. Previous studies investigating medication errors in obstetrics have reported that 65-75% of errors occur during the administration stage [48,49]. When errors result in harm, they are mainly associated with the administration of IV oxytocin and magnesium [49]. One of the reports included in the current investigation provided details of harm in 10 patients due to accidental magnesium overdose administration [31]. However, the article did not evaluate systemic and human factors methodologically. Magnesium administration errors may occur *via* neuraxial routes in obstetric practice. Accidental magnesium administration *via* the intrathecal or epidural route has been reported to cause reversible paraplegia in pregnant women [50]. Some recent investigations suggest medication errors may involve other routine medications also, specifically in obstetric surgical patients (*e.g.*, during caesarean delivery). In one voluntary incident reporting study spanning 14 years, medication errors or issues involving oxytocin, anti-

biotics, vasopressors, and opioids formed 29% of 469 incidents reported during caesarean delivery [51]. In recent times, inadvertent intrathecal administration of tranexamic acid and digoxin during spinal anaesthesia for caesarean section resulted in devastating consequences, including death and permanent paraplegia [52,53].

Our study contrasts with the recent findings of Alves *et al.*'s systematic review on harm prevalence due to medication errors involving high-alert medications, in which the authors did not find evidence that magnesium is associated with a high probability of harm when used in error [54]. In the current study, due to rapid IV magnesium administration, severe adverse outcomes occurred in the form of respiratory arrest only and cardiopulmonary arrest in 61.2% of obstetric and 66.6% of non-obstetric patients. There may be a publication bias because magnesium administration incidents result in fewer harmful effects, or near-miss situations may not get published.

One major contributing factor was the underutilisation of infusion pumps, resulting in inadvertent rapid and extensive dose administration or unsafe handling of infusion devices (*e.g.*, infusion sets, pumps). Magnesium infusion administration typically requires the use of an infusion pump in modern clinical practice. However, it is noteworthy that some errors occurred following the removal of the infusion set from the pump after the termination of magnesium therapy or during the transfer from one clinical location to another. If a specific infusion device is available, the user should be familiar with the infusion pump's safety features, including drug library programming functions [55]. In addition, a standardised magnesium library protocol, automated programming, advanced technological integration (*e.g.*, infusion pump interfaced with a barcode system and electronic health record), monitoring of compliance, and staff training may improve administration safety during the use of advanced infusion pumps [56].

Our study highlights the recurrent, inherent risk of dilution and preparation practices involving large quantities of magnesium in infusion bags. The preparation and dose calculation for magnesium sulphate infusions may also be prone to errors due to the expression of concentration as %w/v, mmol/mL, mg/mL, and g/mL on ampoules or vials of concentrated magnesium sulphate solutions (Fig. 2). A standardised system governing the preparation and dilution of medications, as well as the containers (*e.g.*, syringe size and solvent volume), must be formally established within the hospital or clinical areas to ensure uniform practice at a given site [57]. A description of the established protocol must be available in the working areas [57]. Small-volume pre-mixed pharmacies, commercially prepared syringes, or infusion bags that meet the clinical needs of patients are also options to minimise human errors. Prefilled syringes may be a better option, as magnesium infusion bags can lead to incorrect visual perception with other infusion bags containing medications such as oxytocin, local anaesthetics, and antibiotics. Prefilled syringes eliminate several preparations and other steps susceptible to errors, including labelling [58]. The hospital pharmacy can limit magnesium supply to only lower strengths, facilitate computerised prescribing orders, and provide staff education, such as double-checking. However, further work is required to reach a consensus and achieve consistency regarding magnesium product labels, plasma levels reporting, and the impact of specific prevention measures on reducing magnesium-related medication errors.

There is limited information on medication errors associated with maternal transfer from one location to another or related to the handover of care from one healthcare provider to another. One-third of errors in the current study were associated with patient transfer. Poor communication habits among healthcare providers, incomplete information about ongoing infusions, and inadequate checks, including those of infusion devices upon arrival in new clinical care areas, were common contributing factors. Other communication challenges among maternal care professionals included issues with prescription and documentation. The findings support the conclusions of previous studies that insufficient handling of infusions during patient transfer, inadequate exchange of information, and incomplete handover practices are associated with adverse outcomes, including medication errors [59,60].

Undetected severe respiratory depression due to magnesium toxicity may lead to hypoxia, hypercarbia, cardiac dysrhythmias, and eventually cardiac arrest. The current study presents an opportunity to enhance cardiorespiratory monitoring of patients, particularly those in high-risk obstetric care who receive magnesium infusions. The scenario is somewhat like opioid-induced respiratory depression-related morbidity and mortality. In one adult population study over 6 years, four deaths occurred in 32 patients who experienced postoperative critical respiratory events [61]. In another study of 10 years, the rescue system with continuous surveillance monitoring had a profound effect on death from sedative/analgesic administration in the general care settings [62]. Continuous respiratory monitoring of respiratory physiology parameters, including oxygen saturation (*e.g.*, pulse oximetry), end-tidal $CO_2$ (*e.g.*, capnography), and respiratory rate (*e.g.*, with technology such as thoracic impedance, acoustic plethysmography, and photoplethysmography), may prevent morbidity and mortality in high-risk patients receiving magnesium infusions [63]. Further research is needed to investigate the clinical challenges associated with advanced monitoring in obstetric patients during magnesium infusion, as well as the economic aspects of its implementation.

## Limitations

The study cannot determine the actual incidence rate of IV magnesium errors due to a lack of a denominator. There is a publication bias and a lack of generalizability in the analysis of case reports. The current review might have overestimated the clinical risks associated with the therapeutic use of magnesium. There may be unreported and unpublished near misses involving IV magnesium administration. We have inferred some human and systemic contributory factors from the reports. The harm analysis focused on severe harm and serious outcomes such as respiratory or cardiopulmonary arrest, vegetative state, and death. Some reports' details were incomplete (*e.g.*, infusion devices, educational and training aspects, and monitoring facilities). Many reports did not provide details of neonatal outcomes or follow-up following delivery. Magnesium crosses the placenta, and the foetus cannot metabolise magnesium. Magnesium toxicity has impacted neonatal outcomes in some women. We also could not explore any correlation between serum magnesium levels and clinical consequences or recovery because the administered dose was variable, and the timing of plasma level measurements was also inconsistent.

## Conclusions

Intravenous magnesium administration errors occurred in multiple locations, including obstetric, medical, and surgical wards and acute care settings. Multiple administration steps are vulnerable, including preparing the magnesium dose, changing from loading to maintenance infusion, and cardiorespiratory monitoring during IV use. The plethora of magnesium commercial preparations in varying concentrations and their differing strengths, as expressed on product labels, is confusing. The HFACS demonstrated the existence of deficiencies at all levels, including

skill-based errors in magnesium infusion preparation and administration, substandard practices during the transition of care or transfer of patients, and inadequate organisational processes and climate. Nearly two-thirds of patients developed respiratory arrest or cardiopulmonary arrest during loading or maintenance infusion administration incidents, resulting in adverse outcomes. Applying advanced technological monitoring for early detection of respiratory depression and management may minimise irreversible adverse outcomes. Further international research is required on magnesium administration practices and monitoring during therapeutic use to enhance patient safety.

## CRediT authorship contribution statement

All authors attest that they meet the current International Committee of Medical Journal Editors (ICMJE) criteria for Authorship.

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The authors declare that they have no known competing financial or personal relationships that could be viewed as influencing the work reported in this paper.

## Appendix A. Supplementary data

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